JC09 Rec'd PCT/PTO 02 MAR 2001

FORM PTO-1390 (REV 12-29-99) U S DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE		ATTORNEY'S DOCKET NUMBER
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371		612.39651X00 filed 3/2/01
		U S APPLICATION NO (If known, see 37 CFR 1 5) 09/786232
INTERNATIONAL APPLICATION NO. PCT/FROO/01853	INTERNATIONAL FILING DATE 30 June 2000 (30.06.00)	PRIORITY DATE CLAIMED 02 July 1999 (2.07.99)
TITLE OF INVENTION METHOD INTENDED FOR GRADUAL DEFORMATION OF SEQUENTIAL SIMULATIONS OF A HETEROGENEOUS SUCH AS AN UNDERGROUND ZONE		
APPLICANT(S) FOR DO/EO/US HU, LIN-YING and NOETINGER, BENOIT		

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☐ This express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date
5. ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☒ has been transmitted by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☒ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☐ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ have been transmitted by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☐ have not been made and will not be made.
8. ☒ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern document(s) or information included:

11. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. ☒ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☒ A FIRST preliminary amendment.
    ☐ A SECOND or SUBSEQUENT preliminary amendment.
14. ☐ A substitute specification.
15. ☒ A change of power of attorney and/or address letter.
16. ☒ Other items or information:

PCT REQUEST FORM
International Search Report
International Publication No. WO01/02876
Figs. 1-2,3A-3E,4A-4E,5A-5E,6A-6E,7A-7E,8A-8E,9A-9E
Credit Card Payment Form

528 Rec'd PCT/PTO 02 MAR 2001

U.S. APPLICATION NO. (if known, see 37 CFR 1.5)	INTERNATIONAL APPLICATION NO	ATTORNEY'S DOCKET NUMBER
09/786232	PCT/FROO/01853	612.39651X00

	CALCULATIONS	PTO USE ONLY
17. [X] The following fees are submitted: **BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) :** Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO .... **$970.00** International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO .... **$840.00** International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO .... **$690.00** International preliminary examination fee paid to USPTO (37 CFR 1.482) but all claims did not satisfy provisions of PCT Article 33(1)-(4) .... **$670.00** International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(1)-(4) **$96.00**		
ENTER APPROPRIATE BASIC FEE AMOUNT =	$ 860.00	
Surcharge of **$130.00** for furnishing the oath or declaration later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(e)).	$ 0.00	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	6 - 20 =	0	X $18.00	$ 0.00	
Independent claims	1 - 3 =	0	X $78.00	$ 0.00	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+ $260.00	$ 270.00	
TOTAL OF ABOVE CALCULATIONS =				$ 1,130.00	
Reduction of 1/2 for filing by small entity, if applicable. A Small Entity Statement must also by filed (Note 37 CFR 1.9, 1.27, 1.28).				$ 0.00	
SUBTOTAL =				$ 1,130.00	
Processing fee of **$130.00** for furnishing the English translation later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(f)). +				$ 0.00	
TOTAL NATIONAL FEE =				$ 1,130.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). **$40.00** per property +				$ 40.00	
TOTAL FEES ENCLOSED =				$ 1,170.00	
				Amount to be refunded:	$
				charged:	$

a. [X] A check in the amount of $ 1,170.00 to cover the above fees is enclosed.

b. [ ] Please charge my Deposit Account No. ________ in the amount of $________ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. [X] The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 01-2135. A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

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SIGNATURE

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NAME

26,422

REGISTRATION NUMBER

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4530/00/JC

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant(s): Lin-Ying HU et al

Serial No.: To Be Assigned

Filed: March 3, 2001
(Concurrently Herewith)

For: METHOD INTENDED FOR GRADUAL DEFORMATION OF SEQUENTIAL SIMULATIONS OF A HETEROGENOUS MEDIUM SUCH AS AN UNDERGROUND ZONE

Art Unit:

Examiner:

PRELIMINARY AMENDMENT

Assistant Commissioner
for Patents
Washington, D. C. 20231

March 2, 2001

Sir:

Prior to examination of the above-identified application, please amend the claims as follows:

IN THE CLAIMS:

Please amend claims 3 and 4 as follows:

3. (Amended) A method as claimed in claim 1, comprising gradual deformation of the model representative of the heterogeneous medium simultaneously in relation to the structural parameters and to the random numbers.

4. (Amended) A method as claimed in claim 1, comprising separate gradual deformation of a number n of parts of the model representative of the heterogeneous medium while preserving continuity between these n parts of the model by subdividing the uniform vector into n mutually independent subvectors.

Please insert new claims 5 and 6 as follows:

--5. A method as claimed in claim 2, comprising gradual deformation of the model representative of the heterogeneous medium simultaneously in relation to the structural parameters and to the random numbers.

6. A method as claimed in claim 2, comprising separate gradual deformation of a number n of parts of the model representative of the heterogeneous medium while preserving continuity between these n parts of the model by subdividing the uniform vector into n mutually independent subvectors.--

REMARKS

Claims 1-4 remain in the application. Claims 3 and 4 have been amended. New claims 5 and 6 have been added.

The claims have been amended to remove the multiple dependent claims before filing fee calculation.

Attached hereto is a marked-up version of the changes made to the claims by the current amendment. The attached page is captioned "Version with markings to show changes made."

To the extent necessary, Applicants petition for an extension of time under 37 C.F.R. §1.136. Please charge any shortage in fees due in connection with the filing of this paper, including extension of time fees, to Deposit Account No. 01-2135 (612.39651X00) and please credit any excess fees to such Deposit Account.

Respectfully submitted,

ANTONELLI, TERRY, STOUT & KRAUS, LLP

Donald E. Stout
Registration No. 26,422
(703) 312-6600

Attachment

DES:dlh

"VERSION WITH MARKINGS TO SHOW CHANGES"

CLAIMS

1) A method intended for gradual deformation of a representation or realization, generated by sequential simulation, of a not necessarily Gaussian stochastic model of a physical quantity z in a heterogeneous medium such as an underground zone, in order to constrain it to a set of data collected in the medium by means of previous measurements and observations, relative to the state or the structure thereof, characterized in that it comprises applying a stochastic model gradual deformation algorithm to a Gaussian vector (Y) with N mutually independent variables that is connected to a uniform vector U with N mutually independent uniform variables by a Gaussian distribution function (G), so as to build a chain of realizations u(t) of vector U, and using these realizations u(t) to generate realizations z(t) of this physical quantity that are adjusted to the data.

2) A method as claimed in claim 1, characterized in that a chain of realizations u(t) of vector (U) is defined from a linear combination of realizations of Gaussian vector (Y) whose combination coefficients are such that the sum of their squares is one.

3) A method as claimed in ~~any one of~~ claim~~s~~ 1 ~~or 2~~, comprising gradual deformation of the model representative of the heterogeneous medium simultaneously in relation to the structural parameters and to the random numbers.

4) A method as claimed in ~~any one of~~ claim~~s~~ 1 ~~or 2~~, comprising separate gradual deformation of a number n of parts of the model representative of the heterogeneous medium while preserving continuity between these n parts of the model by subdividing the uniform vector into n mutually independent subvectors.

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528 Rec'd PCT/PTO 02 MAR 2001

PATENT

METHOD INTENDED FOR GRADUAL DEFORMATION OF SEQUENTIAL SIMULATIONS OF A HETEROGENEOUS MEDIUM SUCH AS AN UNDERGROUND ZONE

ABSTRACT

- Method intended for gradual deformation of representations or realizations, generated by sequential simulation, of a not necessarily Gaussian stochastic model of a physical quantity z in a meshed heterogeneous medium, in order to adjust them to a set of data relative to the structure or the state of the medium which are collected by previous measurements and observations.

- It essentially comprises applying a stochastic model gradual deformation algorithm to a Gaussian vector with N mutually independent variables which is connected to a uniform vector with N mutually independent uniform variables by the Gaussian distribution function so as to define realizations of the uniform vector, and using these realizations to generate representations of this physical quantity z that are adjusted to the data.

- Applications for example for visualizing the statistical configuration of a quantity : permeability of an underground reservoir, atmospheric pollution, etc.

FIELD OF THE INVENTION

The object of the present invention is a method intended for gradual deformation of representations or realizations, generated by sequential simulation, of a not necessarily Gaussian stochastic model of a heterogeneous medium, based on a gradual deformation algorithm of Gaussian stochastic models.

The method according to the invention finds applications in underground zones modelling intended to generate representations showing how a certain physical quantity is distributed in an underground zone (permeability z for example) and best compatible with observed or measured data : geologic data, seismic records, measurements obtained in wells, notably measurements of the variation with time of the pressure and of the flow rate of fluids from a reservoir, etc.

BACKGROUND OF THE INVENTION

In patent application FR-98/09,018 is described a method intended for gradual deformation of a stochastic (Gaussian type or similar) model of a heterogeneous medium such as an underground zone, constrained by a set of parameters relative to the structure of the medium. This method comprises drawing a number p (p=2 for example) of realizations (or representations) independent of the model or of at least part of the selected model of the medium from all the possible realizations and one or more iterative stages of gradual deformation of the model by performing one or more successive linear combinations of p independent initial realizations, then composite realizations successively obtained possibly with new draws, etc., the coefficients of this combination being such that the sum of their squares is 1.

Gaussian or similar models are well-suited for modelling continuous quantity fields and they are therefore ill-suited for modelling zones crossed by fracture networks or channel systems for example.

The most commonly used geostatistical simulation algorithms are those referred to as sequential simulation algorithms. Although they are particularly well-suited for simulation of Gaussian models, they do not imply in principle a limitation to this type of model.

A geostatistical representation of an underground zone is formed for example by subdividing it by a network with N meshes and by determining a random vector with N dimensions $Z = (Z_1, Z_2, \ldots Z_N)$ best corresponding to measurements or observations obtained on the zone. As shown for example by Johnson, M.E. ; in « Multivariate Statistical Simulation » ; Wiley & Sons, New York, 1987, this approach reduces the problem of the creation of an N-dimensional vector to a series of N one-dimensional problems. Such a random vector is neither necessarily multi-Gaussian nor stationary. Sequential simulation of Z first involves the definition of an order according to which the N elements $(Z_1, Z_2, \ldots Z_N)$ of vector Z are generated one after the other. Apart from any particular case, it is assumed that the N elements of Z are generated in sequence from Z_1 to Z_N. To draw a value of each element Z_i, $(i = 1, \ldots, N)$, the following operations have to be carried out :

a) building the distribution of Z_i conditioned by $(Z_1, Z_2 .. Z_{i-1})$

$F_c(z_i) = P(Z_i \leq z_i / Z_1, Z_2, \ldots Z_{i-1})$; and

b) drawing a value of Z_i from distribution $F_c(z_i)$.

In geostatistical practice, sequential simulation is frequently used to generate multi-Gaussian vectors and non-Gaussian indicator vectors. The main function of sequential simulation is to determine conditional distributions $F_c(z_i)$ ($i = 1,\ldots, N$). Algorithms and softwares for estimating these distributions are for example described in :

- Deutsch, C.V. et al, « GSLIB (Geostatistical Software Library) and User's Guide » ; Oxford University Press, New York, Oxford 1992.

Concerning drawing the values from distribution $F_c(z_i)$, there also is a wide set of known algorithms.

We consider the inverse distribution method by means of which a realization of Z_i : $z_i = F_c^{-1}(u_i)$ is obtained, where u_i is taken from a uniform distribution between 0 and 1. A realization of vector Z therefore corresponds to a realization of vector U whose elements $U_1, U_2, \ldots, U_N$, are mutually independent and evenly distributed between 0 and 1.

It can be seen that a sequential simulation is an operation S which converts a uniform vector $U = (U_1, U_2, \ldots, U_N)$ to a structured vector $Z = (Z_1, Z_2, \ldots, Z_N)$:

$$Z = S(U) \qquad (1).$$

The problem of the constraint of a vector Z to various types of data can be solved by constraining conditional distributions $F_c(z_i)$ ($i = 1, \ldots, N$) and/or uniform vector $U = (U_1, U_2, \ldots, U_N)$.

Recent work on the sequential algorithm was focused on improving the estimation of conditional distributions $F_c(z_i)$ by geologic data and seismic data integration.

An article by Zhu, H. et al can be mentioned for example : « Formatting and Integrating Soft Data : Stochastic Imaging via the Markov-Bayes Algorithm » in Soares, A., Ed. Geostatistics Troia 92, vol.1 : Kluwer Acad. Publ., Dordrecht, The Netherlands, pp.1-12, 1993.

However, this approach cannot be extended to integration of non-linear data such as pressures from well tests and production records, unless a severe linearization is imposed. Furthermore, since any combination of uniform vectors U does not give a uniform vector, the method for gradual deformation of a stochastic model developped in the aforementioned patent cannot be directly applied within the scope of the sequential technique reminded above.

The method according to the invention thus allows to make the two approaches compatible, i.e. to extend the formalism developped in the aforementioned patent to gradual deformation of realizations, generated by sequential simulation, of a not necessarily Gaussian stochastic model.

DEFINITION OF THE METHOD

The method allows gradual deformation of a representation or realization, generated by sequential simulation, of a not necessarily Gaussian stochastic model of a physical quantity z in a heterogeneous medium such as an underground zone, in order to constrain it to a set of data collected in the medium by previous measurements and observations relative to the state or the structure thereof.

It is characterized in that it comprises applying an algorithm of gradual deformation of a stochastic model to a Gaussian vector (Y) having a number N of mutually

independent variables that is connected to a uniform vector (U) with N mutually independent uniform variables by a Gaussian distribution function (G), so as to define a chain of realizations u(t) of vector (U), and using these realizations u(t) to generate realizations z(t) of this physical quantity that are adjusted in relation to the (non- linear) data.

According to a first embodiment, the chain of realizations u(t) of uniform vector (U) is defined from a linear combination of realizations of Gaussian vector (Y) whose combination coefficients are such that the sum of their squares is one.

According to another embodiment, gradual deformation of a number n of parts of the model representative of the heterogeneous model is performed while preserving the continuity between these n parts of the model by subdividing uniform vector (U) into a number n of mutually independent subvectors.

BRIEF DESCRIPTION OF THE DRAWINGS

Other features and advantages of the method according to the invention will be clear from reading the description hereafter of a non limitative example, with reference to the accompanying drawings wherein :

- Figure 1 shows the medial layer of a realization of a facies model used as a reference, generated by sequential simulation of indicatrices,

- Figure 2 shows the variation with time of the pressure obtained in a well test for the reference model,

- Figures 3A to 3E respectively show five initial realizations of the medial layer of a reservoir zone, constrained only by the facies along the well,

- Figures 4A to 4E respectively show, for these five realizations, the bottomhole pressure curves in the reference model compared with those corresponding to the initial models,

- Figures 5A to 5E respectively show five realizations of the medial layer of the facies model conditioned to the facies along the well and adjusted in relation to the pressure curve obtained by well tests,

- Figures 6A to 6E respectively show, for the five realizations, the bottomhole pressure curves in the reference model compared with those corresponding to the adjusted models,

- Figures 7A to 7E respectively show how the objective functions respectively corresponding to these five examples vary with the number of iterations,

- Figures 8A to 8E show the gradual deformations generated by an anisotropy coefficient change on a three-facies model generated by sequential simulation of indicatrices, and

- Figures 9A to 9E show the local gradual deformations of a three-facies model, generated by sequential simulation of indicatrices.

DETAILED DESCRIPTION OF THE METHOD

We consider a study zone that is subdivided by an N-mesh grid and we try to build realizations or representations of a stochastic model of a certain physical quantity z representing for example the permeability of the formations in the zone. The wanted model must adjust to data obtained by measurements or observations at a certain number of points, and notably to non-linear data.

Adjustment of a stochastic model to non-linear data can be expressed as an optimization problem. $f^{obs} = (f_1^{obs}, f_2^{obs}, f_3^{obs} \ldots f_p^{obs})$ designates the vector of the non-linear data observed or measured in the medium studied (the reservoir zone), and $f = (f_1, f_2, f_3 \ldots f_p)$ the corresponding vector of the responses of the stochastic model of the permeability $Z = (Z_1, Z_2, \ldots, Z_N)$. The problem of constraining stochastic model Z by observations consists in generating a realization z of Z which reduces to a rather low value an objective function that is defined as the sum of the weighted rms errors of the responses of the model in relation to the observations or measurements in the reservoir zone, i.e. :

$$O = \frac{1}{2}\sum_{i=1}^{p}\omega_i(f_i - f_i^{obs})^2$$

where ω_i represents the weight assigned to response f_i. Functions f_i (i=1, 2, ..., p) and objective function O are functions of vector Z. We are thus faced with an optimization problem of dimension N.

In order to extend the formalism developped in the aforementioned patent to the gradual deformation of realizations generated by not necessarily Gaussian sequential simulation, we start from a Gaussian vector with N variables Y_i with i = 1, 2, ..., N, mutually independent, of zero mean and of variance equal to 1, and N mutually independent uniform variables $U_1, U_2, U_3, \ldots U_N$ are defined by :

$$U_i = G(Y_i)\ \forall\ i = 1, 2, \ldots, N$$

where G represents the standardized Gaussian distribution function.

Assuming this to be the case, the gradual deformation algorithm developped within a Gaussian frame is applied to the Gaussian vector $Y = (Y_1, Y_2, \ldots, Y_N)$ in order to build

a continuous chain of realizations of uniform vector $U = (U_1, U_2, \ldots, U_N)$. Given two independent realizations y_A and y_b of Y, the chain of realizations u(t) of vector U obtained with the following relation is defined :

$$u(t) = G(y_a \cos t + y_b \sin t) \qquad (2).$$

For each t, u(t) is a realization of vector U. A vector z(t) which is, for each t, a realization of random vector Z is then obtained by sampling of the conditional distribution $F_c\ (z_i)$ (i=1, 2,..., N) using the elements of vector u(t). Parameter t can consequently be adjusted as in the Gaussian case so as to adjust z(t) to non-linear data. This procedure is iterated until satisfactory adjustment is obtained.

Adjustment of a facies model to pressure data obtained by means of well tests

In order to illustrate application of the stochastic optimization method defined above, we try to adjust a stochastic reservoir model to pressure data obtained by means of well tests. Building of the reservoir model derives from a real oil formation comprising three types of facies : two reservoir facies of good quality (facies 1 and 2) and a reservoir facies of very bad quality (facies 3). Table 1 defines the petrophysical properties of the three facies :

	K_x (md)	K_y (md)	K_z (md)	Φ (%)	c_t (10^{-5} bar^{-1})
Facies 1	10	10	10	17	2.1857
Facies 2	1	1	1	14	2.0003
Facies 3	0.1	0.1	0.001	9	1.8148

In order to represent the specific facies distribution of the oil formation, a binary realization is first generated to represent facies 3 and its complement. Then, in the complementary part of facies 3, another binary realization independent of the first one is

generated to represent facies 1 and 2. The formation is discretized by means of a regular grid pattern of 60x59x15 blocks 15mx15mx1.5m in size. An exponential variogram model is used to estimate the conditional distributions. The main anisotropy direction is diagonal in relation to the grid pattern. The ranges of the variogram of facies 3 in the three anisotropy directions are 300m, 80m and 3m respectively. The ranges of the variogram of facies 1 and 2 in the three anisotropy directions are 150m, 40m and 1.5m respectively. The proportions of facies 1, 2, 3 are 6%, 16% and 78% respectively.

A well test has been carried out by means of a finite-difference well test simulator as described by :

Blanc, G. et al : « Building Geostatistical Models Constrained by Dynamic Data - A Posteriori Constraints » in SPE 35478, Proc. NPF/SPE European 3D Reservoir Modelling Conference, Stavenger, Norway, 1996.

The medial layer of a realization used as the reference model for this validation can be seen in Figure 1. The section of the well that has been drilled runs horizontally through the medial layer of the reservoir model along axis x. The diameter of the well is 7.85cm, the capacity of the well is zero and the skin factors of facies 1, 2 and 3 are 0, 3 and 50 respectively. The synthetic well test lasts for 240 days with a constant flow rate of 5 m^3/day so as to investigate nearly the entire oil field. Figure 2 shows the pressure variation with time.

The objective was to build realizations of the facies model constrained by the facies encountered along the well and by the pressure curve obtained during well testing. The objective function is defined as the sum of the rms differences between the pressure responses of the reference model and the pressure responses of the realization. Since the

dynamic behaviour of the reservoir model is mainly controlled by the contrast between the reservoir facies of good and bad quality, the binary realization used to generate facies 1 and 2 has been fixed first and only the binary realization used to generate facies 3 has been deformed for pressure data adjustment.

The pressure responses resulting from the well tests for the five realizations of Figs.3A to 3E are different from that of the reference model, as shown in Figs.4A to 4E. Starting respectively from these 5 independent realizations, by using the iterative adjustment method above, we obtain, after several iterations, five adjusted realizations (Figs.5A to 5E) for which the corresponding pressure curves are totally in accordance with those of the reference model, as shown in Figs.6A to 6E.

Gradual deformation in relation to the structural parameters

In many cases, sufficient data for deducing the structural parameters of the stochastic model : mean, variance, covariance function, etc, is not available. These structural parameters are often given in terms of a priori intervals or distributions. If their values are wrong, it is useless to seek a realization adjusted to non-linear data. It is therefore essential for applications to be able to perform a gradual deformation of a realization with simultaneous modification of random numbers and structural parameters. The sequential simulation algorithm defined by equation (1) makes it possible to change, simultaneously or separately, structural operator S and uniform vector U. Figs. 8A to 8E show the gradual deformations obtained for a fixed realization of uniform vector U when the anisotropy coefficient is changed.

Local or regionalized gradual deformation

When the observations are spread out over different zones of a formation studied, an adjustment using global deformation would be ineffective because the accordance improvement obtained in a zone could deteriorate it in another zone. It is therefore preferable to apply gradual deformations zone by zone. Consider a subdivision of vector U into a certain number n of mutually independent subvectors U^1, U^2,..., U^n, which allows to perform their gradual deformation individually. Separate application of the gradual deformation algorithm to each subvector U^1, U^2,..., U^n allows to obtain a function of dimension n of uniform vector U :

$$U(t_1,t_2,\ldots,t_n) = \begin{bmatrix} U^1(t_1) \\ U^2(t_2) \\ \vdots \\ U^n(t_n) \end{bmatrix} = \begin{bmatrix} G(Y_a^1 \cos t_1 + Y_b^1 \sin t_1) \\ G(Y_a^2 \cos t_2 + Y_b^2 \sin t_2) \\ \vdots \\ G(Y_a^n \cos t_n + Y_b^n \sin t_n) \end{bmatrix}$$

where Y^i_a and Y^i_b for any i = 1, 2,..., n, are independent Gaussian subvectors. For a set of realizations of Y^i_a and Y^i_b, a problem of optimization of n parameters t_1, t_2,..., t_n is solved to obtain a realization that improves or maintains the data adjustment. This procedure can be iterated until satisfactory adjustment is obtained.

Gradual local deformations thus allow to significantly improve the adjustment speed in all the cases where measurements or observations are spread out over different zones of the medium.

The effect of this gradual local deformation on the three-facies model of Figs. 9A to 9E can be clearly seen in these figures where only the delimited left lower part is affected.

The method according to the invention can be readily generalized to gradual deformation of a representation or realization of any stochastic model since generation of a realization of such a stochastic model always comes down to generation of uniform numbers.

CLAIMS

1) A method intended for gradual deformation of a representation or realization, generated by sequential simulation, of a not necessarily Gaussian stochastic model of a physical quantity z in a heterogeneous medium such as an underground zone, in order to constrain it to a set of data collected in the medium by means of previous measurements and observations, relative to the state or the structure thereof, characterized in that it comprises applying a stochastic model gradual deformation algorithm to a Gaussian vector (Y) with N mutually independent variables that is connected to a uniform vector U with N mutually independent uniform variables by a Gaussian distribution function (G), so as to build a chain of realizations u(t) of vector U, and using these realizations u(t) to generate realizations z(t) of this physical quantity that are adjusted to the data.

2) A method as claimed in claim 1, characterized in that a chain of realizations u(t) of vector (U) is defined from a linear combination of realizations of Gaussian vector (Y) whose combination coefficients are such that the sum of their squares is one.

3) A method as claimed in any one of claims 1 or 2, comprising gradual deformation of the model representative of the heterogeneous medium simultaneously in relation to the structural parameters and to the random numbers.

4) A method as claimed in any one of claims 1 or 2, comprising separate gradual deformation of a number n of parts of the model representative of the heterogeneous medium while preserving continuity between these n parts of the model by subdividing the uniform vector into n mutually independent subvectors.

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(12) DEMANDE INTERNATIONALE PUBLIÉE EN VERTU DU TRAITÉ DE COOPÉRATION EN MATIÈRE DE BREVETS (PCT)

(19) Organisation Mondiale de la Propriété Intellectuelle
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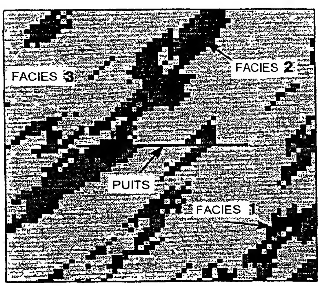
[Suite sur la page suivante]

(54) Title: METHOD FOR GRADUALLY DEFORMING SEQUENTIAL SIMULATIONS OF A HETEROGENEOUS ENVIRONMENT SUCH AS AN UNDERGROUND ZONE

(54) Titre: METHODE POUR DEFORMER GRADUELLEMENT DES SIMULATIONS SEQUENTIELLES D'UN MILIEU HETEROGENE TEL QU'UNE ZONE SOUTERRAINE



(57) Abstract: The invention concerns a method for gradually deforming representations or productions, generated by sequential simulation, of a stochastic model not necessarily Gaussian of a physical quantity z in a meshed heterogeneous environment, so as to adjust them to a set of data concerning the structure or the state of the environment collected by prior measurements and observations. It consists essentially in applying an algorithm gradually deforming a stochastic model to a Gaussian vector with N mutually independent variables, which is linked to a uniform vector with N mutually independent variables by the function of Gaussian distribution so as to define productions of the uniform vector, and in using said productions to generate representations of said physical quantity z, which is set relative to the data. The invention is useful for example to display the statistic configuration of a quantity: the permeability of an underground deposit, atmospheric pollution and others.

(57) Abrégé: Méthode pour déformer graduellement les représentations ou réalisations, générées par simulation séquentielle, d'un modèle stochastique non nécessairement gaussien d'une grandeur physique z dans un milieu hétérogène maillé, afin de les ajuster à un ensemble de données relatives à la structure ou l'état du milieu qui sont collectées par des mesures et observations préalables. Elle comporte essentiellement l'application d'un algorithme de déformation graduelle d'un modèle stochastique à un vecteur gaussien à N variables mutuellement indépendantes, qui est relié à un vecteur uniforme à N variables uniformes mutuellement indépendantes par la fonction de répartition gaussienne de façon à définir des réalisations du vecteur uniforme, et l'utilisation de ces réalisations pour générer des représentations de cette grandeur physique z, que l'on cale par rapport aux données. Applications par exemple pour visualiser la configuration statistique

WO 01/02876 A1

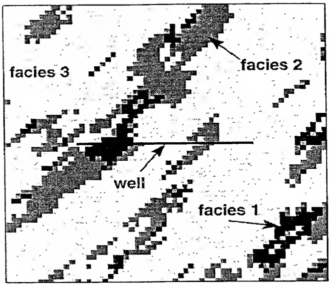


Fig. 1

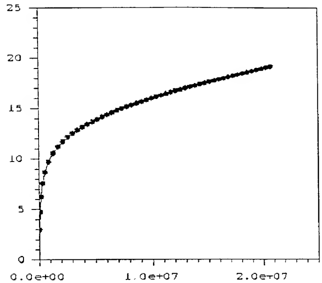


Fig.2

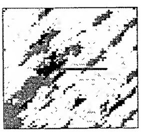


Fig.3A

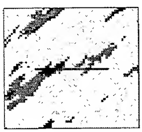


Fig.3B

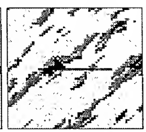


Fig.3C

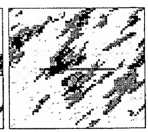


Fig.3D

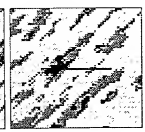


Fig.3E

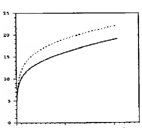


Fig.4A

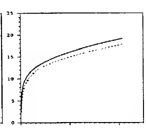


Fig.4B

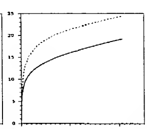


Fig.4C

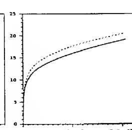


Fig.4D

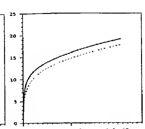


Fig.4E

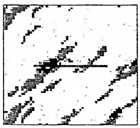


Fig.5A

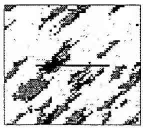


Fig.5B

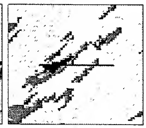


Fig.5C

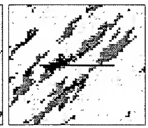


Fig.5D

Fig.5E

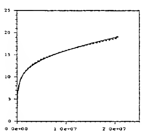


Fig.6A

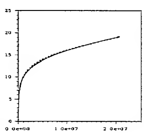


Fig.6B

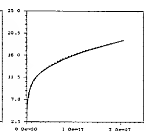


Fig.6C

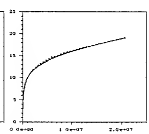


Fig.6D

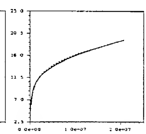


Fig.6E

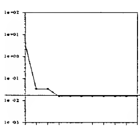


Fig.7A

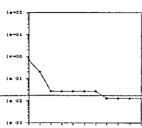
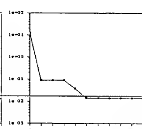


Fig.7B



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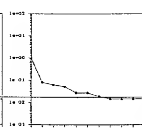

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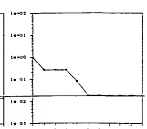

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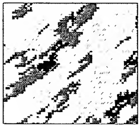
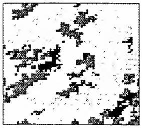


Fig.8A



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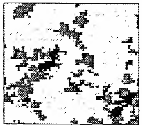

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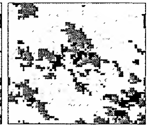


Fig.8D

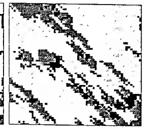
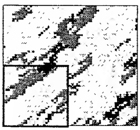


Fig.8E



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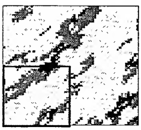

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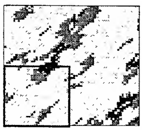

Fig.9C

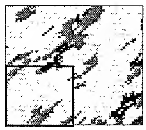

Fig.9D

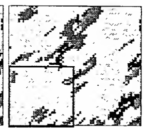

Fig.9E

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DECLARATION AND POWER OF ATTORNEY FILED WITH U.S. DESIGNATED OFFICE UNDER 35 U.S.C. 371(c)(4)

As a below named inventor, I hereby declare that :

My residence, post office address and citizenship are as stated below next to my name, I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled :

METHOD INTENDED FOR GRADUAL DEFORMATION OF SEQUENTIAL SIMULATIONS OF A HETEROGENEOUS MEDIUM SUCH AS AN UNDERGROUND ZONE

the specification of which was filed as PCT International No. PCT/FR00/01853

filed 30th June 2000 And was amended on ____________
(if applicable)

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, § 1.56(a).

I hereby claim foreign priority benefits under Title 35, United states Code, § 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed :

Prior Foreign Application (s) — Priority Claimed

(Number)	(Country)	(Day/Month/Year Filed)	Yes	No
99/08605	FRANCE	02/07/99	☒	☐
			☐	☐
			☐	☐
			☐	☐
			☐	☐

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application :

(Application Serial No.)	(Filing Date)	(Day/Month/Year Filed)

LL

I hereby appoint as principal attorneys; Donald R. Antonelli, Reg. No. 20,296; David T. Terry, Reg. No. 20,178; Melvin Kraus, Reg. No. 22,466; Stanley A. Wal, Reg. No. 26,432; William I. Solomon, Reg. No. 28,565; Gregory E. Montone, Reg. No. 28,141; Ronald J. Shore, Reg. No. 28,577; Donald E. Stout, Reg. No. 26,422; Alan E. Schiavelli, Reg. No. 32,087; James N. Dresser, Reg. No. 22,973 and Carl I. Brundidge, Reg. No. ~~29,621~~ to prosecute and transact all business connected with this application and any related United States application and international applications. Please direct all communications to the following address :

09786232 .030201

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(Full Name) (Signature)

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